High Data Rate Architecture
ICSSC 2017

On the Development and Application of High Data Rate Architecture (HiDRA) in Future Space Networks

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"Keeping the universe connected."

John H. Glenn Research Center at Lewis Field

www.nasa.gov

NASA Needs

- Increase network data throughput to meet future user needs - don't let communications capability constrain the science on our missions

- Accelerate the infusion of optical communications and high data rate RF systems into the operable network

- Develop solutions leveraging commercial partners
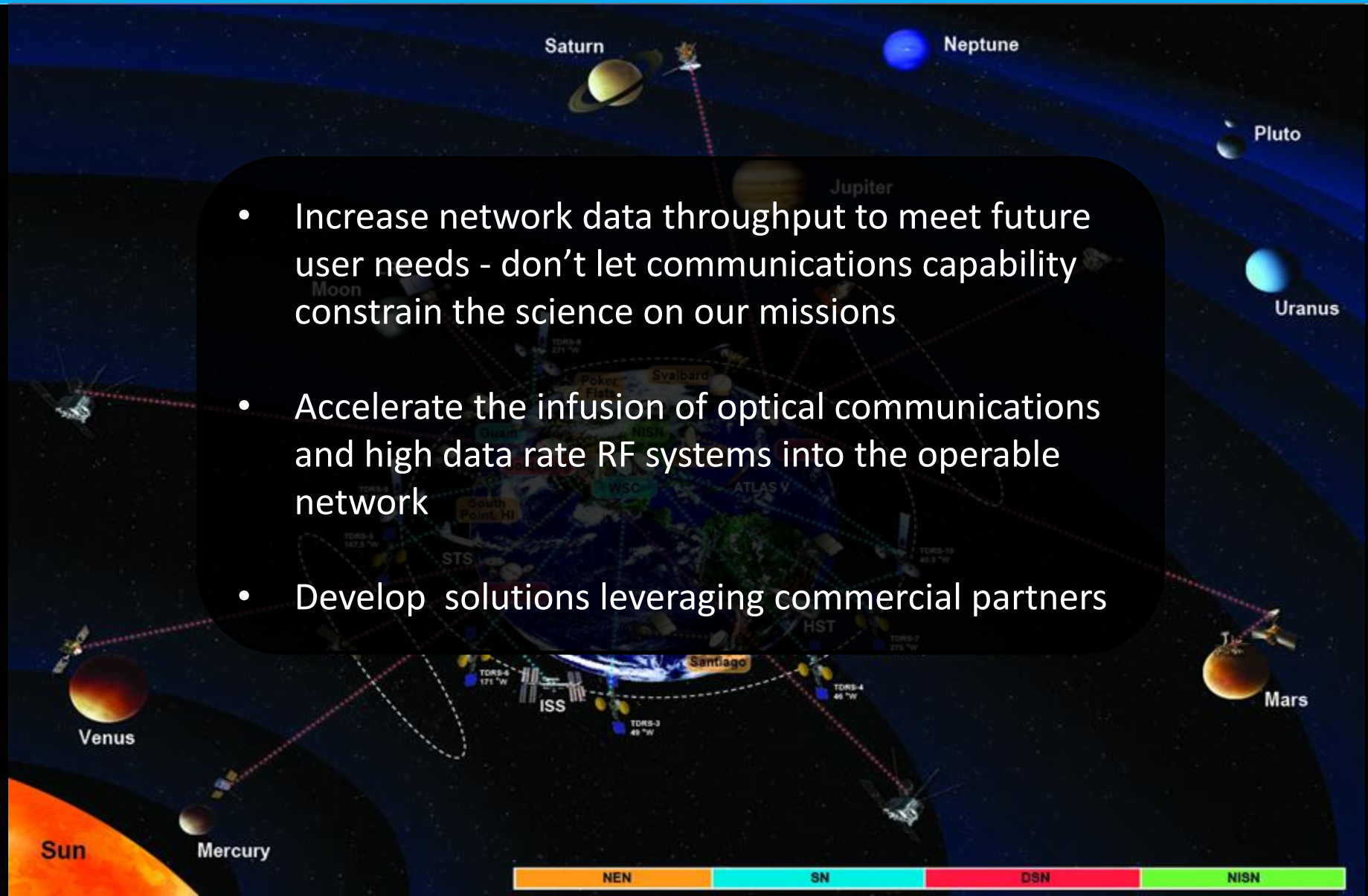
HiDRA Goals

Develop and demonstrate new, high-payoff space technologies that will promote mission utilization of optical and high rate RF communications, thereby expanding the capabilities of NASA's exploration, science, and discovery missions.

Provide reconfigurable store, forward and routing capabilities to support evolving mission requirements and developing infrastructure, and provide feedback paths to enable the foundations for realizing system cognition and autonomy.

Implement proactive and reactive link management solutions to utilize network nodes in an optimal manner.

HiDRA
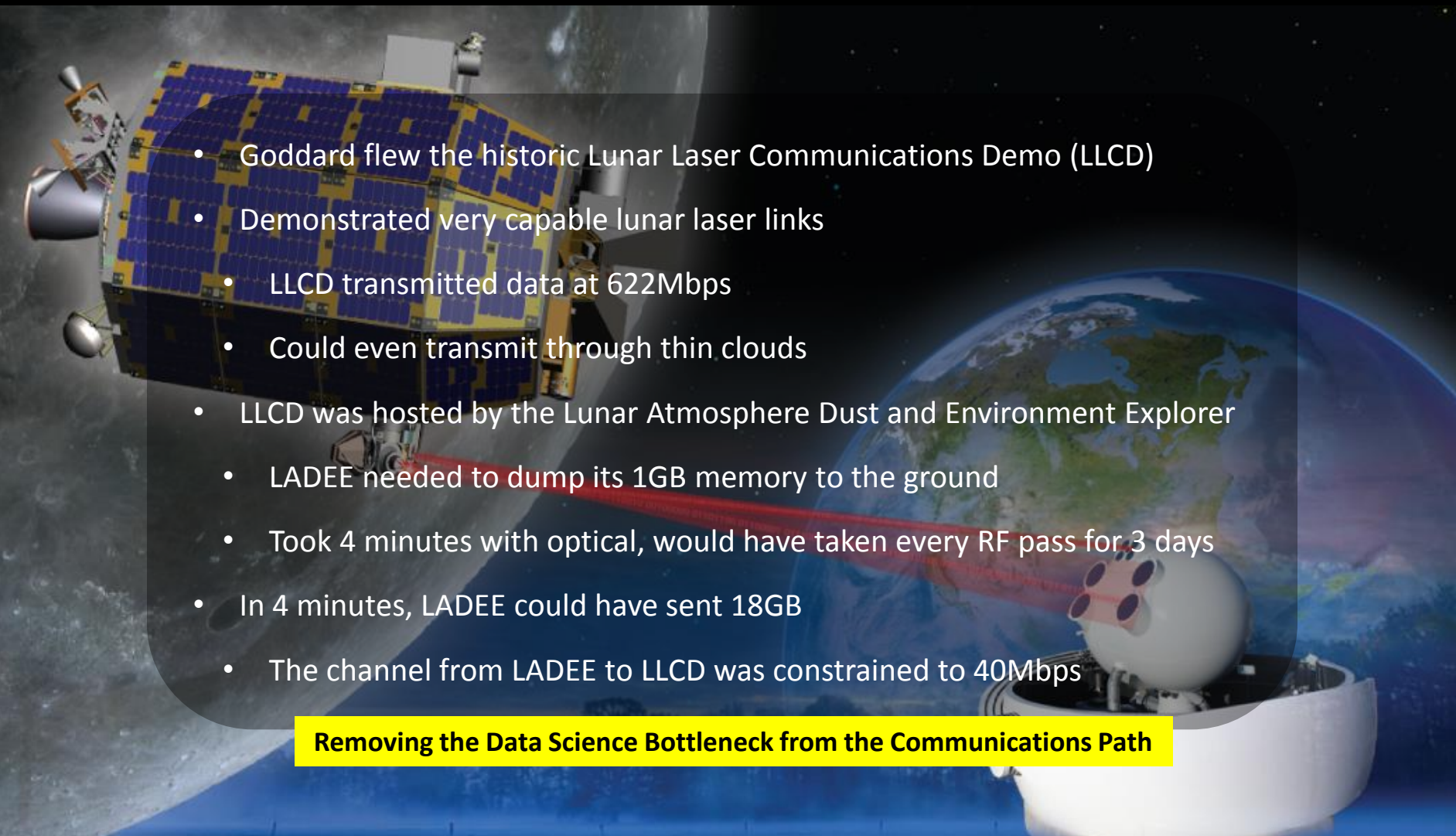## Technology and Standards Division (TSD) Objectives

- Provide a buffering and routing flight data architecture servicing an array of scientific instruments reaching 10 Gbps transfer rates; capable of supplying one or more high rate communications radios with extensibility to 200 Gbps.

- Serve as a space networking node, and demonstrate advanced protocols and concepts enabling daily 100 TB information transfers.

- Prototype and demonstrate performance of key components to increase to TRL5, leading to integrated system demonstration

- Characterize and quantify system performance over a variety of relevant parameters and conditions.

- Recommend architecture, implementation options, data storage sizing strategies, interface specifications, standards adherence, and reliability parameters for future operational systems.

Enabling High Rate RF & Optical Communication Links

HiDRA
Citing Precedent - LLCD

- Goddard flew the historic Lunar Laser Communications Demo (LLCD)

- Demonstrated very capable lunar laser links

  - LLCD transmitted data at 622Mbps

  - Could even transmit through thin clouds

- LLCD was hosted by the Lunar Atmosphere Dust and Environment Explorer

  - LADEE needed to dump its 1GB memory to the ground

  - Took 4 minutes with optical, would have taken every RF pass for 3 days

- In 4 minutes, LADEE could have sent 18GB

  - The channel from LADEE to LLCD was constrained to 40Mbps
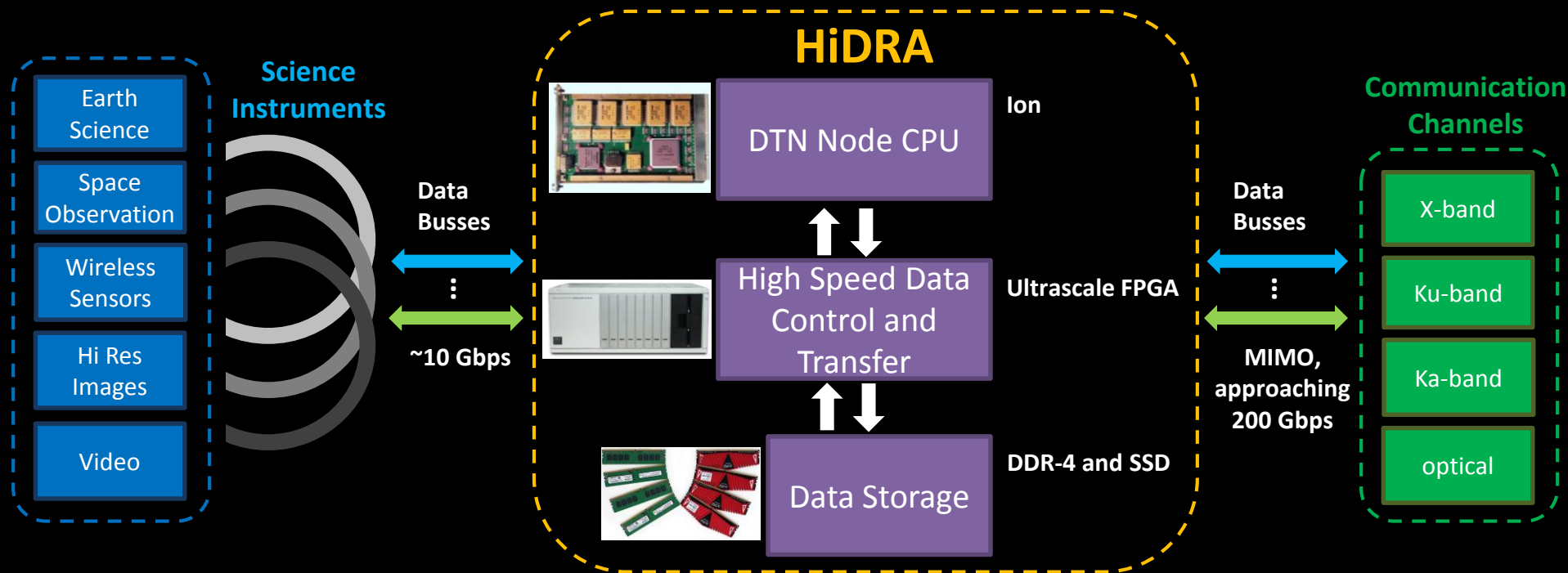
Removing the Data Science Bottleneck from the Communications Path

Generalized HiDRA

*Designing for Portability and Scalability Facilitating Commercialization*

HiDRA

Science Instruments

Earth Science

Space Observation

Wireless Sensors

Hi Res Images

Video

Data Busses

⋮

~10 Gbps

DTN Node CPU — Ion

High Speed Data Control and Transfer — Ultrascale FPGA

Data Storage — DDR-4 and SSD

Communication Channels

X-band

Ku-band

Ka-band

optical

Data Busses

⋮

MIMO, approaching 200 Gbps

○ **Features simultaneous read and write capability**
○ **Supports the capability to store, carry and forward 100 Tb of data daily**

Prototyped systems currently operating in the laboratory

ISS Optical Link Operations
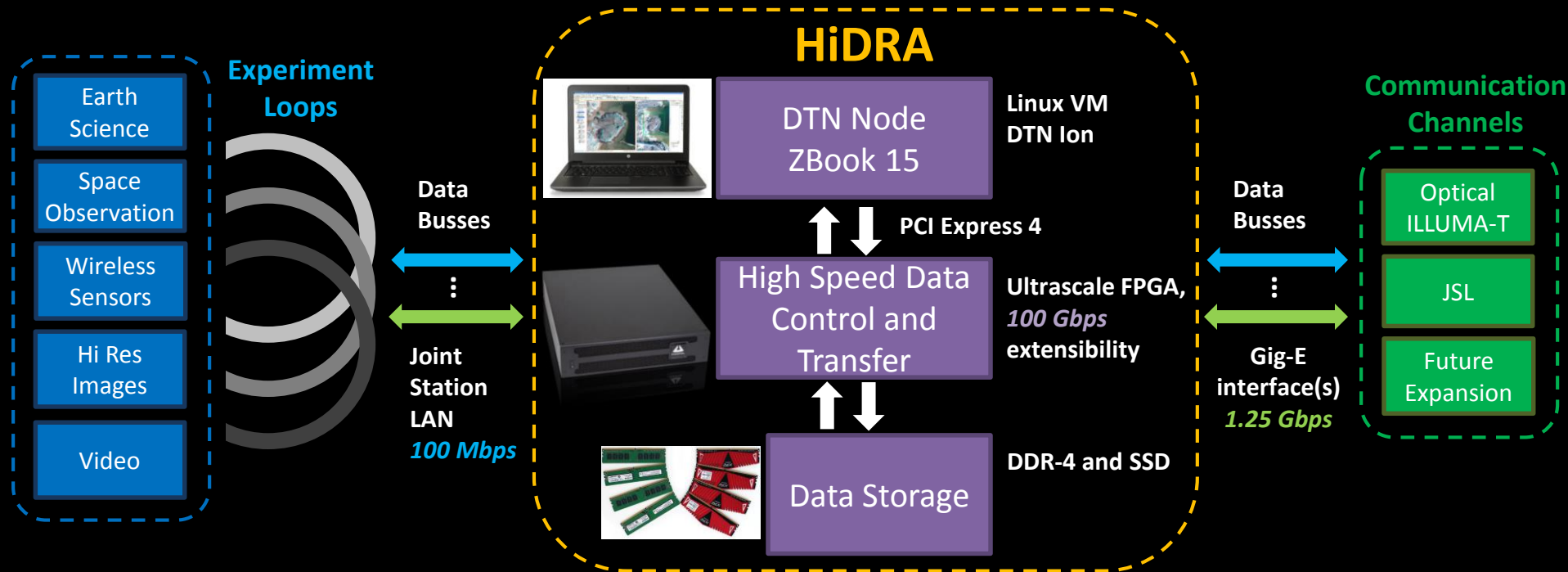## (Courtesy of NASA GSFC)
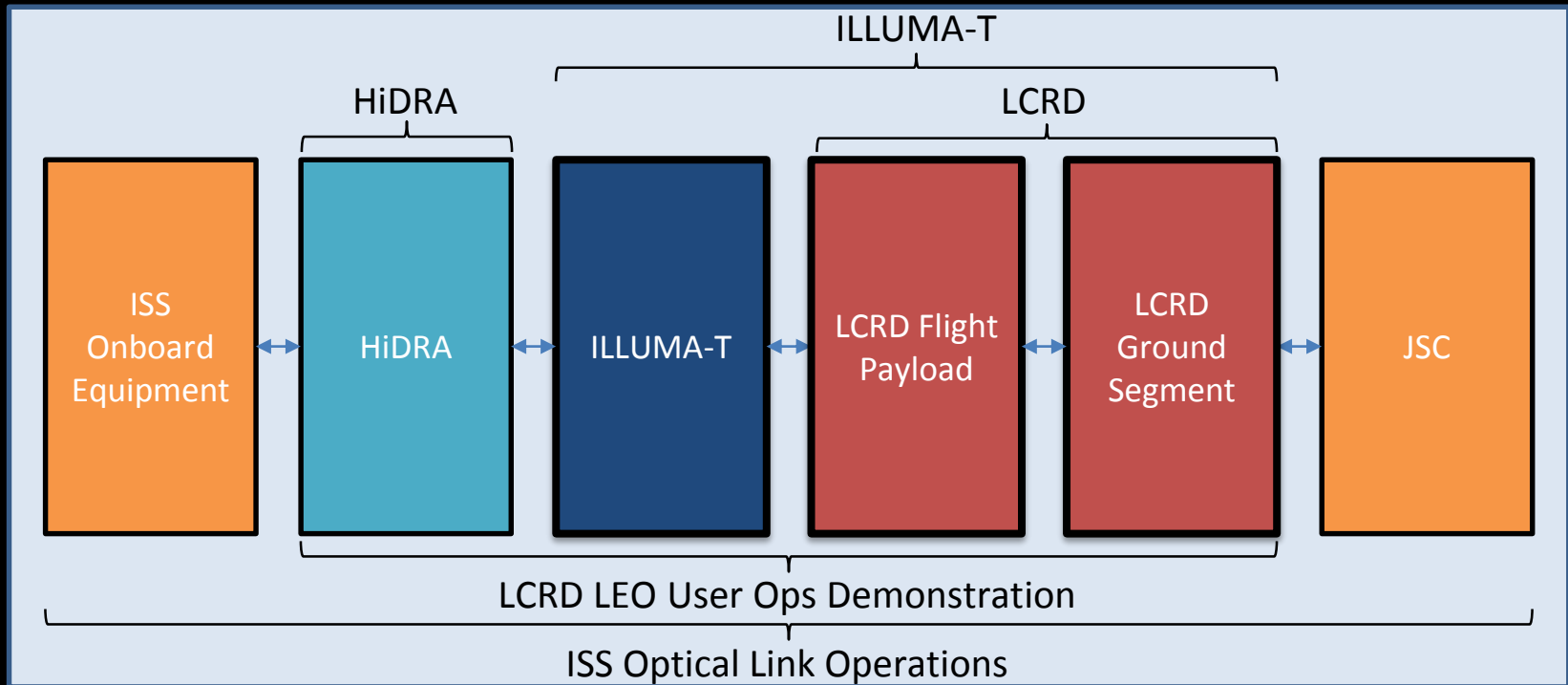
- # Objective
  - – Provide optical link path for ISS data delivery
- # Minimum Success
  - – Delivery of ISS data via LCRD

HiDRA Implementation on ISS

Providing a High Speed Interface for the ILLUMA-T Payload Linking to LCRD

HiDRA

Experiment Loops

- Earth Science
- Space Observation
- Wireless Sensors
- Hi Res Images
- Video

Data Busses

Joint Station LAN
100 Mbps

DTN Node ZBook 15 — Linux VM DTN Ion

PCI Express 4

High Speed Data Control and Transfer — Ultrascale FPGA, *100 Gbps* extensibility

DDR-4 and SSD

Data Storage

Communication Channels

Data Busses

Gig-E interface(s)
1.25 Gbps

- Optical ILLUMA-T
- JSL
- Future Expansion

- o **Features simultaneous read and write capability**
- o **Supports the capability to store, carry and forward *30 Tb* of data daily**

Focus on hardware & software implementation to increase data rates
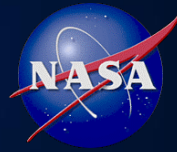
HiDRA
Evolution

HiDRA began…
- As a spinoff of iROC
- As an effort to create a path for advances in communications
  - At all levels – networking, optical…

HiDRA is still these things, and…
- We are using FPGAs to implement a *water tower of data* approach
  - This allows us to transcend internal bus arbitration and so forth
  - It also lets work with various vintages of communications

The current focus…
- Put HiDRA on the ISS to work with ILLUMA-T
- Add SDN capability
- Work with industry

HiDRA
Software and Hardware

Software

- We are building a driver to flow data between BittWare cards
  - We can treat our current HiDRA as NICs
  - We have the capability to store, carry, and forward data
- Right now we use Ethernet/Aurora
  - We are investigating software support for 10G / 25G IP core
- We are constructing web-based software for operation visualization
  - Shows statistics and provides data for network management

Hardware

- Our hardware supports the capability above
- We are procuring a 10G/25G IP core for FPGA
  - While we wait for the PR, we are using a demo license
- Researching available instrumentation
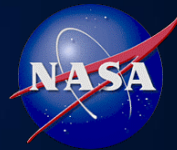
Philosophy

- "High Data Rate" is about the network …
  - Manage getting data off of a node and toward a sink
  - Buffer large amounts of data
    - Fill during periods of disconnection …
    - … and then drain when you can
- … but also about other things, too!
  - Scaling a network is not *just* about making links faster!
    - We *do* want to do that, but …
    - … we also need global optimizations to reduce end-to-end traffic
  - High data rate implies an ***entire service catalog*** …
    - Caching, security, management, etc.
    - Rebuild some services to tune for space hardware
  - … as modern networked applications require *lots* of services!

Implementation

Goal: Take HiDRA philosophy …

    Adaptable, useful, multi-tier architecture

    Synthesis of hardware and software to enable networking

… and prototype it onto some hardware …

    Enter: BittWare cards

        256 GB RAM

        400 Gbps of network (fibre channel) I/O

        Rather powerful Xilinx FPGA

        PCIe host-card interface

            Using four lanes

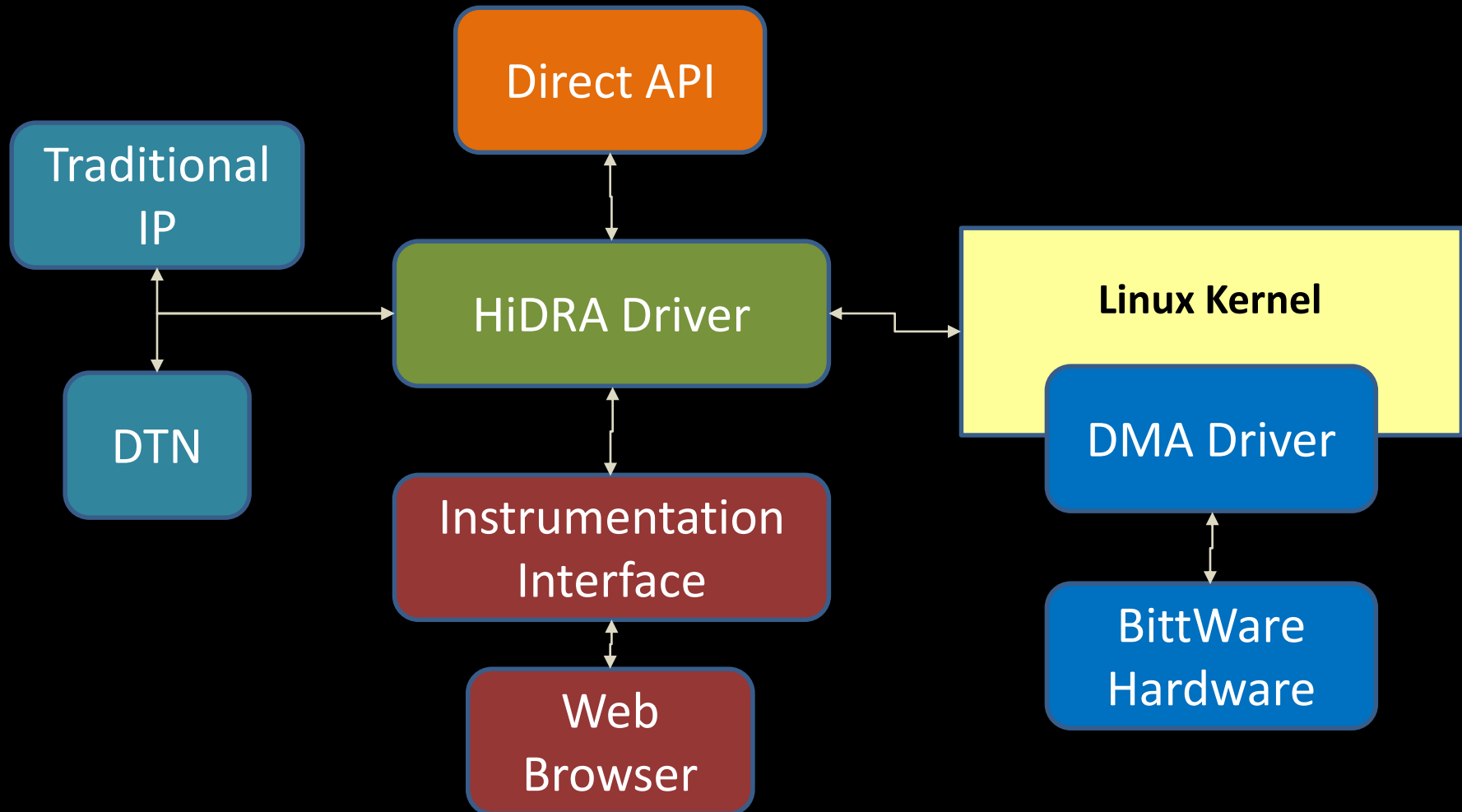… while being mindful of available resources

    Read: don't overdo it

Decision: start with store / carry / forward

    We'll still look at other stuff later …

So, what does a prototype for this subsystem look like? Well …

Current Software

Direct API

Traditional IP

DTN

HiDRA Driver

Linux Kernel

DMA Driver

Instrumentation Interface

Web Browser

BittWare Hardware
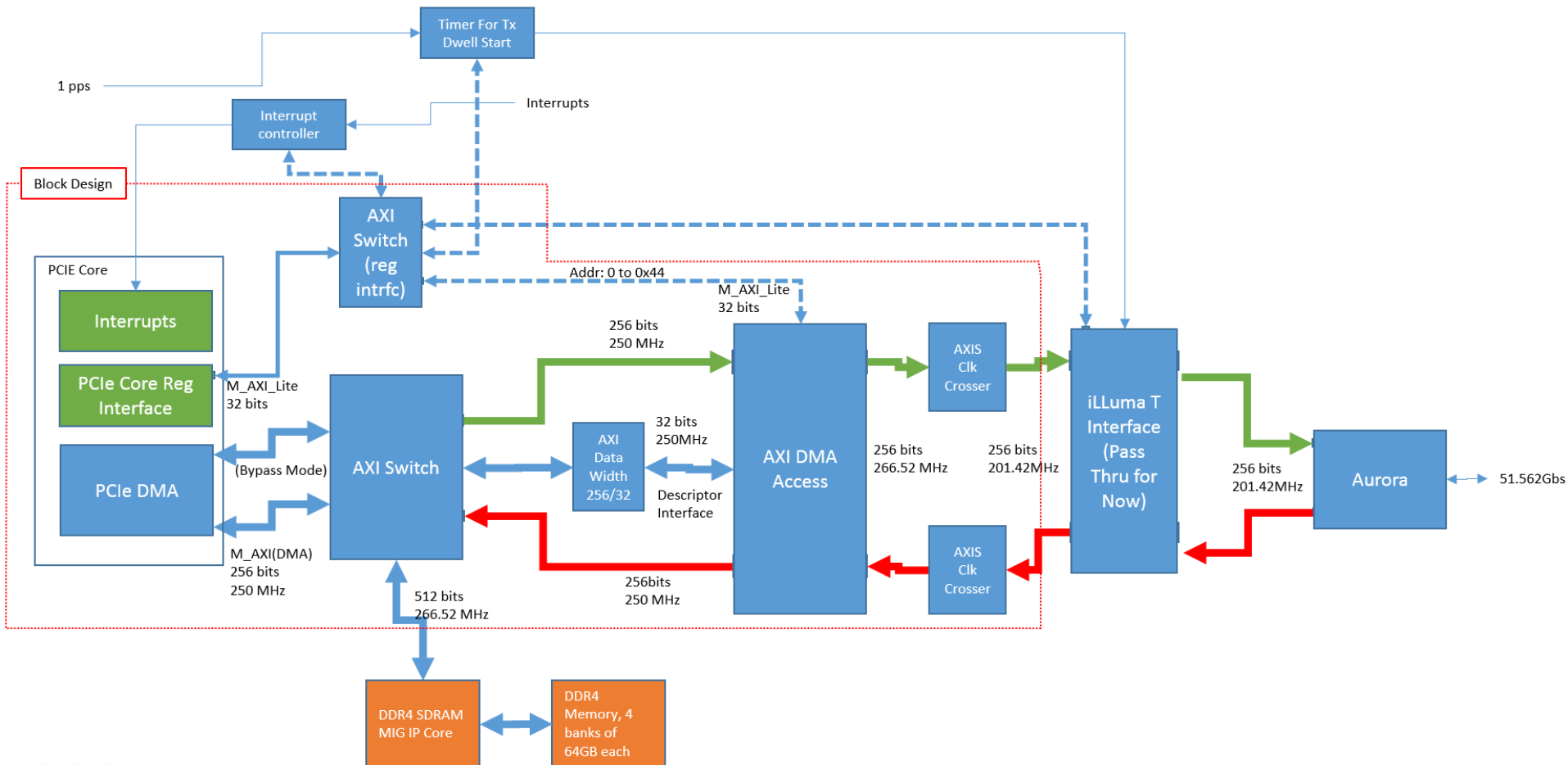
HiDRA: Status

- First iteration of core software is completed
  - Quick prototype intended to demonstrate functionality
- Next iteration will take longer
  - Ideal case: build custom drivers
    - Drivers are a significant bottleneck in proof-of-concept
  - Build instrumentation / monitoring user interface
- Also: add hardware acceleration paths to FPGA
  - Build specific functions into FPGA that can be invoked
  - Need to talk about hw / sw interface for this …
    - … as well as the specific functions to be included …
      - … which will likely grow over time

Current Hardware
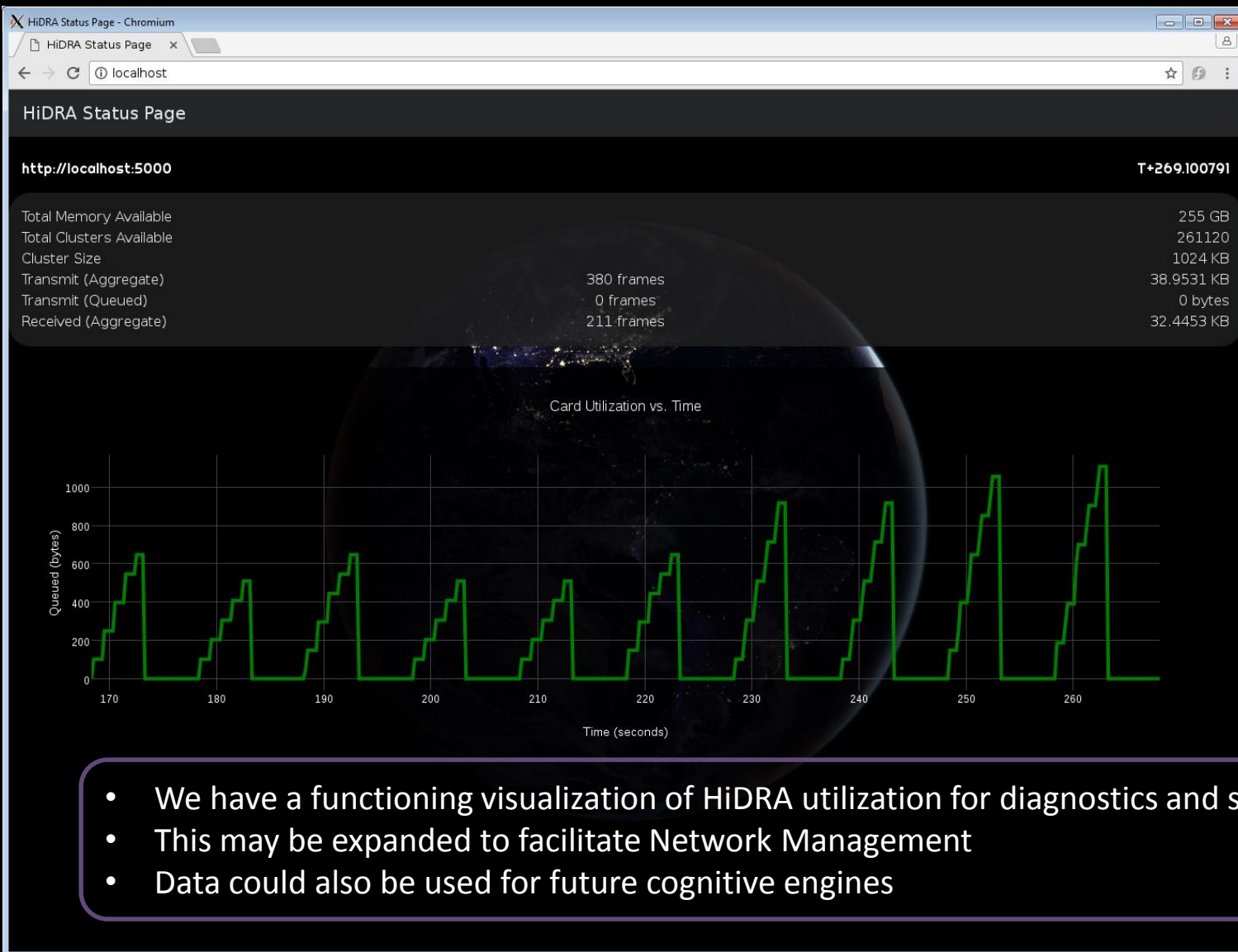## ISS Reference Implementation

HiDRA
Visualization of HiDRA Status

- We have a functioning visualization of HiDRA utilization for diagnostics and sanity checking
- This may be expanded to facilitate Network Management
- Data could also be used for future cognitive engines

HiDRA and Quantum Key Distribution
QSwitch

QSwitch:

- A prototype network device capable of digitizing, framing, time-stamping, and storing high-rate instrument data.
- It includes a customized reference implementation of HiDRA built on top of an UltraScale+ FPGA for data plane processing & digitization.
- Linux-based control and monitoring software is included as well.
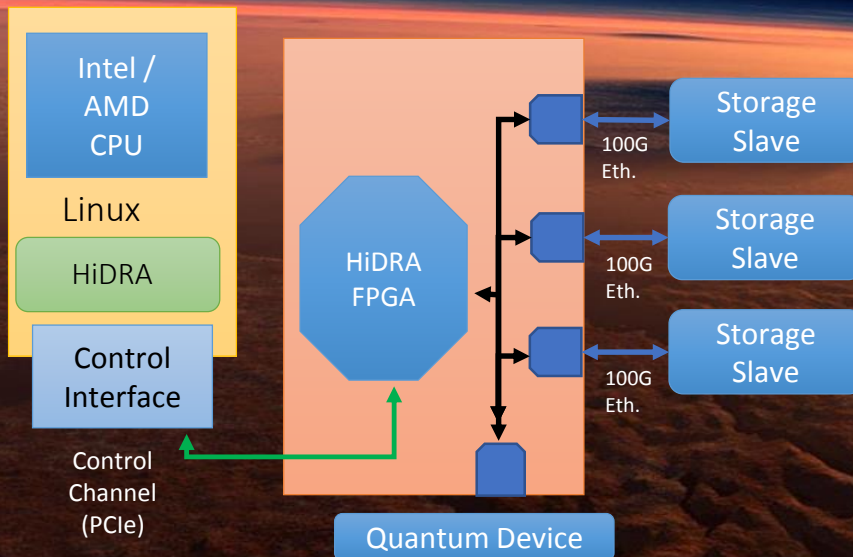
HiDRA Cross-Project Collaboration

- Project need: Quantum Key Distribution
  - Time-stamping
  - Store raw data for now, for post-processing
  - Integrate with real-time processing in the future
  - High-rate instrument data storage
  - High-rate instrument data networking
- Approach
  - Uses existing hardware and software
    - BittWare boards, HiDRA control prototype
  - Some extension is necessary
    - Digitization, framing, and timestamps
      - Reusable for other projects!
    - Real-time quantization and pre-processing
  - Horizontal scaling to support high-rate storage
  - Should not require one-off work to execute
    - HW and SW is on path for both projects
- Benefits
  - Avenue to prove viability of HiDRA and QKD
    - Naturally evolves both projects
  - Offers real value to ongoing experiment
  - Low additional effort and cost

Intel / AMD CPU

Linux

HiDRA

Control Interface

Control Channel (PCIe)

HiDRA FPGA

Storage Slave
100G Eth.

Storage Slave
100G Eth.

Storage Slave
100G Eth.

Quantum Device

HiDRA
Next Steps

- Implement HiDRA solution for ISS
- Test 10/25 Gbps Ethernet connection
- Survey of discovery protocols for local networks
    - Prototype of our own should be done within next month or so
    - LLDP-based capability advertisements
    - Close coordination with STRS to enumerate radio capabilities
- Integration of SDN platform in HiDRA
    - Exploring hierarchical software-defined networking approach
    - Determine architectures to address a range of mission classes